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UTILITY LIFELINE LESSONS LEARNED, JANUARY 17, 1994, NORTHRIDGE EARTHQUAKE

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ABSTRACT

A M_W 6.7 earthquake occurred January 17, 1994, centered in the Northridge community of Los Angeles, California, USA. The earthquake had significant impact on utility lifelines, in addition to damage to residential and commercial buildings, and freeways. The estimated total damage was approximately $20 billion and there were approximately 58 fatalities. A discussion is presented on the lessons relearned from past earthquakes, especially the 1971 San Fernando, CA earthquake. Also new lessons learned for lifeline utility performance and emergency response from the Northridge earthquake. The conclusions and recommendations from the Northridge earthquake which will prove of value in improving the performance of utility lifelines in future events.

KEYWORDS

Lifelines; utilities; lifeline earthquake engineering; water; wastewater; electric power; telecommunication; gas; liquid fuel; emergency response.

INTRODUCTION

An earthquake occurred at 4:31 a. m. (PST) on Monday, January 17, 1994, the epicenter was located 35 kilometres (20 miles) from the center of Los Angeles in the Northridge community of Los Angeles, California, USA. The magnitude was M_W 6.7 (Caltech). The earthquake had significant impact on lifelines, in addition to damage to residential and commercial buildings, and freeways. The estimated damage was approximately $20 billion and there were approximately 58 fatalities. A discussion is presented on the lessons relearned from past earthquakes, especially the M 6.4, 1971 San Fernando, CA earthquake. Also new lessons learned for lifeline utility performance and emergency response from the Northridge earthquake. The conclusions and recommendations from the Northridge earthquake which will prove of value in improving the performance and emergency response of utility lifelines in future events.

LIFELINES

Lifelines are those services vital to the health, safety, human and social activities of the community and particularity to the functioning of an urban industrialized society. Lifelines are critical for the emergency response and recovery of a community after a disaster such as an earthquake. Lifelines include electric power, communication, transportation (highways, airports, railroads and harbors) water, wastewater, natural gas, and liquid fuel systems.

NORTHRIDGE EARTHQUAKE LIFELINE PERFORMANCE

Electric service was lost throughout the Los Angeles area, the first time in history the whole city was blacked out. In addition to the entire city of Los Angeles, 600,000 customers in nearby cities from Montebello to Santa Barbara lost power, and because of the interconnection of power grids, lights were flickering through out the western United States and Canada. Damage to high voltage ceramic equipment in substations and several downed transmission lines caused most of this outage. Thermal generation facilities performed well.

Water supply to Southern California is provided by local groundwater basins, storage reservoirs and imported supplies from the Colorado River and northern California. The earthquake disrupted five pipelines from northern California serving the Simi, Santa Clarita and San Fernando Valleys which supplied three water treatment plants. Water treatment plants received minor damage and were available for operation. The most significant damage to the distribution pipeline network was within the epicentral area. There were approximately 1,700 leak repairs by the water utilities in the Simi, Santa Clarita and San Fernando Valleys. "Boil water" notices were issued through out the area, after repairs these notice were lifted under the jurisdiction of the California Department of Health Services. Field personnel reported ductile iron pipe with rubber gasket joints performed very well. Pumping stations and groundwater wells performed well except for the loss of power. Old steel tanks were damage including the inlet-outlet piping. Prestressed concrete tanks performed well.

The most significant damage to wastewater treatment plants occurred in the Santa Clarita Valley, to lessor degree in the San Fernando Valley and no damage in the Simi Valley. Plants lost commercial power, had concrete cracking and damage to mechanical systems due to sloshing. Sewer lines were damaged in the epicentral area, but of gravity operation continued to flow. Sewer replacement programs were initiated, after video inspection, later in the year. Pump lift stations were not damaged, but lost power supply.

The natural gas supplier experienced about 151,000 outages, of which approximately 123,000 were customer initiated closures. There were almost 775 non corrosion or corrosion related repairs of metallic distribution mains and services. The limited amount of polyethylene pipe installed performed well. There were approximately 14,000 leaks in customer facilities. Restoration of customer service was very time consuming, because of the need for gas service personnel to check the internal gas piping and gas appliances before turning on the service. New gas transmission lines with butt welded joints performed well. Some old transmission lines with oxygen-acetylene welded joints failed.

There are three major liquid fuel pipelines which transport crude oil from the San Joaquin Valley to the Los Angeles basin refineries, two of which performed without damage. The third, a 10-inch pipeline, had a leak in a cracked weld near the Santa Clara River in Santa Clarita Valley, and a half dozen leaks, again principally in welds at other locations along the pipeline. A oil spill occurred into the river which was cleaned within a few days.

As is common in this type of event, there is a tremendous increase in the number of telephone call attempts. This earthquake produced this typical telephone congestion or overload. Main switch/transmission equipment performed extremely well despite evidence of strong shaking. Main cause of line disruption is circuit boards being unseated from the connectors or malfunction of the cards. Overhead ironworks and floor anchorage, also, functioned extremely well. However, buckled hanger

rods, buckled and bent auxiliary bars, bent cable trays, pounding of bars against side-walls and loose friction clips were evident. The structural damage in several facilities was severe enough to limit access to the facility. Most vulnerable components are support systems. All central offices experienced power failure and backup generator problems; overload is the main cause of generator problems.

Lifelines were important in emergency response and restoring the community after the Northridge earthquake. Telecommunications, radio and electronic media played a valuable role in directing emergency response for essential services and the repairing of damaged lifelines. Water supply was necessary where available for public fire protection. Highways and roads were used to move rescue, repair, fire and medical teams and their supplies and equipment to the damaged areas. Although the Northridge earthquake was severe, the lifeline disruption only represented a small percentage of inconvenience to the population served within greater earthquake impact area of western Los Angeles and eastern Ventura Counties.

The 1994 Northridge event showed improvement in the seismic performance of lifelines from the 1971 San Fernando earthquake. Among the facilities and equipment installed and built, under modern seismic codes, since 1971, with good seismic performance, but not totally inclusive, is dead tank and bulk oil circuit breakers, telephone operating equipment, dams, steel and concrete tanks, wells, pumping stations and treatment plants. Welded steel pipe with butt welded joints, ductile iron pipe with rubber gasket joints and polyethylene pipe also performed well.

The 1994 Northridge event demonstrated the vulnerability of lifelines in essential facilities, such as, hospitals, fire stations and emergency operating centers. Roof top mechanical and electrical equipment are not generally designed for seismic forces. Small breaks in water lines and automatic sprinklers caused flooding in lower floors, Roof top HVAC (heating, ventilating, and air conditioning) equipment was damaged which caused malfunction of other systems within the building.

Some lifeline agencies made seismic vulnerability assessments of their facilities to determine vulnerability to damage of their system. The assessment prioritized and scheduled any required seismic mitigation. Most lifelines agencies had an emergency response and recovery plan.

LIFELINES CONCLUSIONS, LESSONS, and RECOMMENDATIONS

1. Lifelines played an important role in emergency response and restoring the community after the Northridge earthquake. Telecommunications, radio and electronic media played a valuable role in directing emergency response for essential services and the repairing of damaged lifelines. Water supply was necessary where available for public fire protection. Highways and roads were used to move rescue, repair, fire and medical teams and their supplies and equipment to the damaged areas. Although the Northridge earthquake was severe, the lifeline disruption only represented a small percentage of inconvenience to the population served within greater earthquake impact area of western Los Angeles and eastern Ventura Counties.

2. The 1994 Northridge event showed significant improvement in the seismic performance of lifelines from the 1971 San Fernando earthquake. Among the facilities and equipment installed and built, under modern seismic codes, since 1971, with good seismic performance, but not totally inclusive, is dead tank and bulk oil circuit breakers, telephone operating equipment, dams, steel and concrete tanks, wells, pumping stations and treatment plants. Welded steel pipe with butt welded joints, ductile iron pipe with rubber gasket joints and polyethylene pipe also performed well.

3. Since 1971, emergency response plans were prepared, tested and implemented by lifeline agencies. In California, April has been designated as the earthquake awareness month for testing the plans, the anniversary of the 1906 San Francisco earthquake. Most lifeline agencies coordinated with their local emergency operations centers. Many agencies received mutual aid support from other similar lifelines or

contractors. Emergency response plans need to be updated and continually practiced. More formal mutual aid and contractor agreements need to be initiated.

4. Above ground tanks usually have either one or two pipes, with valves, rigidly connected to the tank to provide for the filling the tank and draining the tank to meet the peak water demands in the water service area. In the Northridge earthquake, there were cases were the piping or valves broke because the differential movement between the tank and the piping. Several methods have been developed for providing a more flexible connection between the tank and the piping to withstand the differential movement. There needs to be further study on economical and other methods of preventing storage tank inlet/outlet piping damage due to differential movement.

5. Older steel tanks not seismically designed and constructed under AWWA standards for welded steel tanks (AWWA D-100) suffered buckling at the bottom (elephants foot bulge), in the shell and roof. There is a need to seismically retrofit these older tanks.

6. Water pipe use bell and spigot pipe almost exclusively for welded steel pipe. Bells are fabricated by an expansion process to provide the larger diameter for the bell. There were a number of instances in the Northridge earthquake were a bell was cracked at the curvature point where the bell changes diameter. Preliminary investigation indicates a need to study the seismic strength of welded steel bell and spigot joints and how to improve the seismic performance of the joint.

7. Most damage to the water distribution piping occurred in cast iron mains with rigid joints and old steel pipe subject to corrosion. Although there is limited ductile iron pipe with rubber gasket joints installed, field personnel reported, the seismic performance of this pipe was very good. Programs are needed to replace this older pipe in seismically active areas.

8. There continues to be a problem in the strength of high voltage 230 and 500 kv ceramic (porcelain) insulators. At a number of substations the insulators broke at the base, while the metal support structure was undamaged. There needs to be further study on improving the seismic performance of high voltage insulators.

9. The loss of power affected the operation of number of wells, pumping stations and treatment plants without a emergency power supply or do not have the capacity to provide for all their essential services. There is a need to provide or enlarge the emergency generation capacity to cover all essential operations. Portable generators with "quick electrical connections" will also be of value.

10. Most of the emergency back up power supplies worked, however there is a continuing need to regularly test these emergency generators under load; to have adequate fuel for a longer term commercial power outage; provision for transferring fuel from the storage tank to the day tank, when the electric pumps are out of service.

11. Sloshing and shaking in large basins in water filtration and water reclamation plants has cause damage in the 1989 Loma Preita and 1994 Northridge events. Although not critical, the damaged equipment can cause malfunction of other equipment. As an example sloshing caused the jamming of the chain drive sludge scrapers in seven out of 44 final clarifiers of water reclamation plant. There is a continuing need to consider sloshing in the design of mechanical equipment and baffles in large basins of water and wastewater treatment plants.

12. Customer water, gas and electrical service was disrupted to a portion of the population impacted by in the greater earthquake area and for a short period of time considering the intensity of the earthquake. Most of this disruption was due to distribution system damage and structural damage to residences, buildings and freeways. Redundancy was provided in distribution system networks and alternate supplies from other sources for electric and gas supplies and storage, groundwater basins and alternate aqueduct systems for water supplies. Redundancy continues to play an important role in the restoration of lifeline services.

13. In the Northridge event 123,000 gas customers turned off their gas services. This required gas personnel, supplemented by personnel from other gas companies, to make a time consuming consumer piping, structure and gas appliance inspection before relighting the gas service. There is continuing need to educate the media and gas customers to not to turn off their gas unless they hear or smell gas or have physical damage to their structure or gas appliances.

14. There is the potential for fire if electrical service is restored to a damaged structure in which there is an unidentified gas leak. Coordination is required in the restoration of gas and electric service to avoid any potential for fires. Especially there is a need to coordinate these activities during a search and rescue operation. This is similar to the coordination needed to restore water and sewer facilities.

15. The 1994 Northridge event demonstrated the vulnerability of lifelines in essential facilities, such as, hospitals, fire stations and emergency operating centers. Roof top mechanical and electrical equipment are not generally designed for seismic forces. Small breaks in water lines and automatic sprinklers caused flooding in lower floors, Roof top HVAC equipment was damaged which caused malfunction of other systems within the building. Internal lifelines in essential facilities require seismic design. There is also a need for emergency electric and water supplies.

16. The Northridge earthquake identified several areas were there is a need for enhancing the ability of lifeline employees in their emergency response and recovery activities. This event cause transportation problems, because of the closed freeways, for lifeline employees to get from their homes to their work location. Alternate work locations or telecommuting where feasible should be used.

17. There is need for emergency food, water and housing; and adequate cash to purchase these items, for lifeline workers in the epicentral areas. Because there is a potential for potable water, gas and electricity not being available, restaurants and motels may not be in operation.

18. There is need for a communications plan, which has been tested for lifeline employees and families to notify each other of their well being. This would allow employees to report directly to a restoration effort without worrying about their families. This was no necessary in the Northridge event because most people were already at home at 4:31 a. m. in the morning.

19. Non-emergency response lifeline employees, in advance of an emergency, should be assigned and trained in emergency response activities. For government lifelines there is a need to document repairs for FEMA (Federal Emergency Management Administration) reimbursement which could be done by non-emergency response personnel.

20. Boil water notices were issued in the epicentral area. Consideration should be given to developing a mobile water quality laboratory to expedite, in the field after repairs have been made, the determination if the water is safe for drinking.

21. Currently bacteriological testing takes several days to determine if the water is not contaminated with fecal coliform and safe for drinking. Research should be done to expedite this process in order the boil notice may be lifted sooner.

22. Large diameter pipes, conduits and tunnels were repaired from the inside in the Northridge event. In the United States, the Occupational Health and Safety Act (OSHA) requires pretraining, specific air testing to determine the presence of poisonous gases and emergency breathing equipment before entering a confined space.

23. Air and vacuum valves on pipelines are an inverted pendulum above the ground surface. In the Northridge event many valves toppled, had cracked bodies or damaged floats (balls). The damage may have been caused by transient pressures in the pipeline. A study is required to improve the performance of these valves in an earthquake.

24. The Northridge event there was good performance of structures and equipment which had been seismically upgraded from the 1971 San Fernando event. Seismic upgrade of lifeline equipment, buildings and facilities is very costly requires prioritizing, budgeting and some form of innovative financing. Innovative financing research is required to further improve the seismic performance of lifelines.

25. All lifeline agencies should make seismic vulnerability assessments of their facilities to determine vulnerability to damage of their system. The assessment should prioritize, schedule and budget any required seismic mitigation.

26. All lifelines agencies should have an emergency response and recovery plan. The plan should be practiced and updated on a regular basis.

27. Lifeline emergency response personnel are concerned for the safety of their family and the stability of their house after an earthquake. In the Northridge event one water agency provided family counseling while another agency with their own engineering staff, not involved in the recovery operation, offered their services to help employees with their home earthquake inspections.

28. In the Northridge and previous earthquakes there has been significant damage to water distribution networks causing lack of supply to the people for drinking, cooking and sanitary purposes and water supply for fire suppression. Construction and beverage water trucks, water tank trailers, portable tanks, fire hydrant hose bibb adaptions, and portable hose and pipeline systems have been used. Emergency response plans should include emergency water supply element and designate a specific organization to manage the emergency water supply.

29. On Balboa Boulevard in Granada Hills in the Northridge event a collocation of lifelines occurred. There were nine lifelines including the street at this location (gas, water, sewer, petroleum, telephone, cable television, power, and street lighting) A zone of tension and compression occurred approximately 300 metres (1,000 feet) apart causing damage to one sewer, two gas and two water lines. A fire erupted eventually causing the burning of five homes and the severing the overhead telephone, cable television, power and street lighting. Studies are required to develop mitigation scenarios for essential collocated lifelines.

30. Pipeline repairs have been documented in the 1989 Loma Prieta and 1992 Landers/Big Bear, California, earthquakes using the geographical information system (GIS). American Society of Civil Engineers, Technical Council on Lifeline Earthquake Engineering (ASCE-TCLEE) created the Pipeline Failure Data Base for these events. The Northridge earthquake pipeline repairs is also being documented using GIS. GIS identifies the repairs by latitude and longitude and provides characteristics of the repair. In California, a system is being developed to determine an early assessment of damage using damage reports from past earthquakes, GIS and almost real time information as to the location and magnitude of earthquakes. This information could be of value to assist lifeline agencies in the directing their response for repair and recovery.

REFERENCES

Field investigation and data for this report was mostly gathered by the author with assistance of the American Society of Civil Engineers, Technical Council on Lifeline Earthquake Engineering - Earthquake Investigation Team.